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Evaluating Hardwood and Pinebark Media for Container Grown Woody Ornamentals

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ABSTRACT

Twenty-two media containing either pinebark or hardwood bark with soil, sand, or peat in various combinations were evaluated for plant growth and media characteristics. In general, weigela grew best in Metro Mix 500 and hardwood bark media, lilac responded equally to both series of barks, and viburnum grew best in media containing pinebark. The percent air pore space was greatest in 100% pinebark and higher in pinebark media than hardwood bark. The media pH was slightly higher in the hardwood bark mixes than pinebark in July. The pH tended to decrease in almost all mixes in August. By September the pH of hardwood bark mixes began to increase while the pinebark media continued to decrease.

INTRODUCTION

In the Northern U. S., hardwood bark has become, within the past 10 years, the predominant ingredient in the media for the production of container grown woody landscape plants (1, 2, 3, 4, 5, 6, 8). Pinebark has been the primary component in container media in the Southern U. S. (7) but only recently has become available in the North at prices competitive with native hardwood bark. As a result of its availability and with the associated production problems with hardwood bark relating to pH, variability in composition, and composting, Ohio growers are inquiring about the feasibility of using pinebark in their program.

In an attempt to determine plant response, to monitor variability in pH, and to measure air pore space, a study was initiated to compare hardwood bark and pinebark media alone and in combinations with soil, peat, and sand in various proportions. The advantages, if any, of soil, peat, and sand as ingredients in a container media have been questioned at times, but one or more are used by most growers in their production media. Generally, soil is incorporated as a source of mineral elements and to improve the cation exchange capacity, peat to decrease the pH, and sand to add weight to reduce the tipping of larger containers in wind.

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TABLE 1.—Plant Height Following One Growing Season in Various Container Media.

Production Media		Vegetative Growth in Inches Weigela	Lilac	Viburnum
Metro Mix 500		19.4 a*	10.8 ab	11.7 abc
Soil - 100%		10.3 c	4.4 d	2.3 h
Hardwood Bark	100%	15.4 bcd	10.7 ab	6.0 fg
Hardwood Bark + Soil	1:1	16.8 bc	10.4 ab	8.0 fg
Hardwood Bark + Soil	3:1	15.9 bcd	11.2 ab	9.2 abcdef
Hardwood Bark + Soil	5:1	15.4 bcd	10.2 ab	8.6 cdefg
Hardwood Bark + Peat	1:1	19.7 a	9.0 abc	8.1 def
Hardwood Bark + Peat	3:1	16.1 bcd	10.4 ab	6.5 efg
Hardwood Bark + Peat	5:1	16.3 bc	11.3 ab	6.6 efg
Hardwood Bark + Sand	1:1	16.8 bc	8.1 bcd	7.3 efg
Hardwood Bark + Sand	3:1	15.1 bcd	11.9 ab	6.7 efg
Hardwood Bark + Sand	5:1	14.7 cd	10.3 ab	5.1 g
Pinebark	100%	14.7 cd	8.3 bc	9.7 abcde
Pinebark + Soil	1:1	16.1 bcd	12.8 a	9.8 abcde
Pinebark + Soil	3:1	16.2 bc	11.8 ab	12.6 a
Pinebark + Soil	5:1	16.2 bc	10.6 ab	8.9 bcdef
Pinebark + Peat	1:1	16.6 bc	7.9 bcd	12.3 ab
Pinebark + Peat	3:1	16.0 bcd	6.1 cd	10.1 abcd
Pinebark + Peat	5:1	17.7 ab	11.7 ab	9.8 abcde
Pinebark + Sand	1:1	15.9 bcd	6.3 cd	9.8 abcde
Pinebark + Sand	3:1	13.6 d	8.7 bc	8.8 bcdef
Pinebark + Sand	5:1	14.8 cd	7.9 bcd	8.6 cdefg

*Letters followed by dissimilar letters within columns are significantly different at the 5% level.

TABLE 2.—Plant Dry Weight Following One Growing Season in Various Container Media.

Production Media		Dry Weight in Grams Weigela	Viburnum	Lilac
Metro Mix 500		56.0 ab*	7.8 bcd	14.2 a
Soil - 100%		16.6 h	1.2 e	3.3 b
Hardwood Bark	100%	36.2 efg	3.7 de	9.9 ab
Hardwood Bark + Soil	1:1	33.1 fg	4.2 cde	11.9 a
Hardwood Bark + Soil	3:1	30.1 g	8.5 bcd	13.3 a
Hardwood Bark + Soil	5:1	37.5 defg	5.7 cde	14.2 a
Hardwood Bark + Peat	1:1	48.3 abcd	7.6 bcd	14.3 a
Hardwood Bark + Peat	3:1	44.9 abcdef	3.7 de	14.8 a
Hardwood Bark + Peat	5:1	47.0 abcde	4.0 cde	12.8 a
Hardwood Bark + Sand	1:1	56.3 a	4.5 cde	13.9 a
Hardwood Bark + Sand	3:1	42.3 cdef	3.8 de	13.8 a
Hardwood Bark + Sand	5:1	38.1 defg	2.1 a	11.3 a
Pinebark	100%	39.5 defg	10.9 ab	12.4 a
Pinebark + Soil	1:1	38.7 defg	9.4 abc	13.8 a
Pinebark + Soil	3:1	44.1 bcdef	12.2 ab	11.6 a
Pinebark + Soil	5:1	47.7 abcde	11.3 ab	10.9 a
Pinebark + Peat	1:1	52.6 abc	14.2 a	11.6 a
Pinebark + Peat	3:1	43.1 cdef	12.4 ab	8.9 ab
Pinebark + Peat	5:1	39.5 defg	11.4 ab	12.6 a
Pinebark + Sand	1:1	45.6 abcde	9.0 abcd	8.1 ab
Pinebark + Sand	3:1	37.7 defg	9.3 abc	9.5 ab
Pinebark + Sand	5:1	37.5 defg	7.8 bcd	9.8 ab

*Letters followed by dissimilar letters within columns are significantly different at the 5% level.

TABLE 3.—Air Pore Space of Various Container Media Following One Growing Season.

Production Media	Percent Pore Space	Production Media	Percent Pore Space
Soil - 100%	7.3 i*	Metro Mix 500	19.0 ef
Hardwood Bark 100%	22.4 cde	Pinebark 100%	35.8 a
Hardwood Bark - Soil 1:1	10.0 hi	Pinebark - Soil 1:1	17.1 fg
Hardwood Bark - Soil 3:1	22.7 cde	Pinebark - Soil 3:1	25.1 bcd
Hardwood Bark - Soil 5:1	25.1 bcd	Pinebark - Soil 5:1	25.9 b
Hardwood Bark - Peat 1:1	10.5 hi	Pinebark - Peat 1:1	20.6 def
Hardwood Bark - Peat 3:1	13.1 gh	Pinebark - Peat 3:1	25.9 bc
Hardwood Bark - Peat 5:1	19.3 ef	Pinebark - Peat 5:1	27.0 bc
Hardwood Bark - Sand 1:1	11.1 hi	Pinebark - Sand 1:1	9.0 i
Hardwood Bark - Sand 3:1	13.6 gh	Pinebark - Sand 3:1	23.4 cde
Hardwood Bark - Sand 5:1	17.1 fg	Pinebark - Sand 5:1	24.5 cde

*Letters followed by dissimilar letters within columns are significantly different at the 5% level.

MATERIALS AND METHODS

Nine plants each of *Weigela florida, Syringa vulgaris,* and *Viburnum opulus* were potted into each of 22 different media. All plants were potted into 1 gallon Zarntainers and grown in the container research nursery on The Ohio State University campus. The plants were potted June 11, 1979, all fertilized with Osmocote 18-6-12, 8-9 month formulation on June 15, watered from overhead, sprayed for pests as needed, and evaluated on September 25, 1979.

Prior to potting, 5 lb/yd^3 of 0-20-0 were incorporated into the hardwood bark media. Added to the pinebark media were 6 lb of limestone, 2 lb of gypsum, 5 lb of 0-20-0, 5 lb of Esmigran, and 1 lb of Aqua-Gro, a wetting agent. Hardwood and pinebark were mixed into media containing either soil, Canadian sphagnum peat moss, or silica sand. In addition, comparisons were made with 100% hardwood bark, 100% pinebark, 100% soil, and Metro Mix 500, a commercial combination of principally pinebark.

There were three replications each of 22 treatments with three plants/species/treatment.

RESULTS AND DISCUSSION

The tallest weigela plants were produced in Metro Mix 500 and hardwood bark-peat 1:1 (Table 1). Weigela dry weight was highest in hardwood: sand 1:1, Metro Mix 500, and hardwood bark:peat media (Table 2). Growth of weigela was the least satisfactory in 100% soil.

Lilac growth was satisfactory in both hardwood and pinebark media (Table 2), although the tallest plants were generally produced in pinebark:soil, hardwood bark media, and Metro Mix 500 (Table 1). Growth of lilac was poor in 100% soil.

The largest viburnum plants were grown in pinebark:soil 3:1, pinebark:peat 1:1, and Metro Mix 500 (Table 1). The highest dry weight was noted in the pinebark series of media (Table 2). The response of viburnum was poorest in 100% soil and hardwood bark:sand 5:1.

The poor growth of all three species in 100% soil can be explained by poor drainage as water remained in the top of the containers long after watering, while water in all other media drained quite rapidly. The percent air pore space of 100% soil at the September harvest date was only 7.3, which was significantly lower than all other media (Table 3). The highest percentage of air pore space was in 100% pinebark and subsequently the pinebark media were, in most instances, higher than similar media with hardwood bark. When sand or soil was incorporated into hardwood or pinebark at a 1:1 ratio, the air pore space was significantly reduced.

A major concern of nurserymen producing plants in hardwood bark has been the variability of pH with an initial decline followed by an increase, with values

TABLE 4.—pH Levels of Various Container Media in July, August, and September.

Production Media		Media pH		
		July 6	August 5	September 6
Metro Mix 500		5.6	5.1	5.5
Soil - 100%		6.1	5.7	6.9
Hardwood Bark	100%	6.0	5.2	5.8
Hardwood Bark + Soil	1:1	6.2	5.7	6.3
Hardwood Bark + Soil	3:1	6.2	5.8	6.2
Hardwood Bark + Soil	5:1	6.0	5.7	6.0
Hardwood Bark + Peat	1:1	5.5	5.3	5.4
Hardwood Bark + Peat	3:1	5.8	5.2	5.1
Hardwood Bark + Peat	5:1	6.0	5.2	5.3
Hardwood Bark + Sand	1:1	6.1	5.8	4.8
Hardwood Bark + Sand	3:1	6.2	5.4	5.5
Hardwood Bark + Sand	5:1	5.6	5.6	5.8
Pinebark	100%	5.5	5.8	4.9
Pinebark + Soil	1:1	5.8	5.7	5.5
Pinebark + Soil	3:1	6.1	6.0	5.8
Pinebark + Soil	5:1	5.8	5.7	5.7
Pinebark + Peat	1:1	5.1	5.0	5.0
Pinebark + Peat	3:1	5.3	5.0	4.6
Pinebark + Peat	5:1	5.5	5.2	4.9
Pinebark + Sand	1:1	6.2	—	5.1
Pinebark + Sand	3:1	5.8	5.4	5.8
Pinebark + Sand	5:1	5.7	5.3	5.3

becoming strongly alkaline by the second growing season. In this study, the pH was monitored 1, 2, and 3 months following planting. The same pattern described above was noted in most hardwood bark media, with a decline in pH in August and an increase by September. Most media containing pinebark, however, decreased slightly throughout the growing season.

The decline in pH of the pinebark media may prove advantageous to Ohio container producers because many are using alkaline sand and most are irrigating with water with a pH of more than 7.0.

It is easier for a producer to correct an acidic pH than it is to lower an alkaline media. The alkaline pH will result in minor element deficiencies more readily than the acidic media. Iron deficiency has been a serious concern for many producers using hardwood bark and substituting pinebark for hardwood bark may reduce this problem.

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Fly Ash as a Medium Amendment for Container Grown Ornamentals

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ABSTRACT

Royal beauty cotoneaster *(Cotoneaster dammeri* C. K. Schneid. 'Royal Beauty') and Hicksii taxus *(Taxus* x *media* Rehd. 'Hicksii') were grown in media amended with various levels of aggregated fly ash. In general, no differences in root or shoot growth were noted in either species as a result of the medium in which they were grown. High B levels were observed in the leaf tissue of taxus as the level of the aggregated fly ash in the media increased, while no differences in B levels were noted in the leaf tissue of the cotoneaster. Both Cu and B concentrations in the root tissue of taxus increased with increasing levels of aggregated fly ash in the medium.

INTRODUCTION

The increased demand for the generation of electricity from coal in the United States will result in the annual production of fly ash in excess of 100 million tons per year (2). Even though some of this fly ash is utilized in the construction industries, many utilities face an ever-increasing disposal problem.

While fly ash has proven beneficial in land reclamation efforts, the fineness of the particles has limited its usefulness as an amendment for container-grown nursery crops, where larger sized particles are desirable. Since the fineness of the fly ash particles is undesirable for container grown plant production, a lightweight fly ash aggregate, manufactured via a patented process, was utilized in these studies.

As a result, the following studies were undertaken to evaluate the usefulness of several aggregated fly ash products in media used in the production of woody nursery crops.

METHODS

Studies were initiated in 1978 utilizing various proportions of fly ash and composted hardwood bark for the production of two container grown nursery crops. On April 11, uniform cuttings of cranberry cotoneaster *(Cotoneaster dammeri* C. K. Schneid. 'Royal Beauty') and on May 23, 1-year-old liners of Hicksii yew *(Taxus* x *media* Rehd. 'Hicksii') were potted in 2.4 liter plastic nursery pots in five different media. Treatments included a 4:1 (v/v) composted hardwood bark/sand medium as the control and four media composed of varying ratios (v/v) of composted hardwood bark /aggregated fly ash (see Table 2 for composition).

TABLE 1.—Elemental Analysis of Aggregated Fly Ash.

Element	Concentration ppm
Phosphorus	397.6
Potassium	898.9
Calcium	6242.0
Magnesium	607.8
Iron	3200.0
Zinc	25.2
Aluminum	98.9
Copper	29.7
Boron	66.3
Lead	17.2
Chromium	10.9
Cadmium	3.4
Nickel	36.4
Sodium	495.6

The aggregated fly ash used in this study was sieved and screened, with 88% of the material being between 3.2 and 6.3 mm in diameter. A complete chemical analysis for the fly ash material used in these studies is presented in Table 1.

Plants were arranged in a completely randomized design with four replications (three plants per replicate) of each treatment. Fertilizer was applied weekly at the rate of 200 ppm N in the form of a 20N to 16.7P to 8.7K soluble fertilizer.

On August 8, cotoneaster roots and shoots were dried to obtain root and shoot dry weights. *Taxus* dry weights were obtained on January 16. Samples were analyzed using emission spectrographic analysis for P, K, Ca, Mg, Mn, Fe, Si, Na, B, Cu, Zn, Al, Sr, Ba, and Mo.

All variables were statistically analyzed by analysis of variance and the Waller-Duncan k-ratio t-test at the 5% level.

RESULTS

Physical Characteristics

At the termination of this study, bulk density and porosity had increased with increasing proportions of the aggregated fly ash (Table 2). Only the

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TABLE 2.—Effects of Hardwood Bark Amended With Various Levels of Aggregated Fly Ash on the Physical Characteristics of Media.

Treatment (v:v)	Bulk Density B/cc	Porosity %	pH	Soluble Salts (microohms x 100)
4:1 Hardwood Bark/ Sand	0.77	15.0	6.8	450
5:1 Hardwood Bark/ Fly Ash	0.50	21.0	6.9	480
1:1 Hardwood Bark/ Fly Ash	0.64	24.0	6.8	560
1:2 Hardwood Bark/ Fly Ash	0.69	23.0	6.5	460
1:4 Hardwood Bark/ Fly Ash	0.76	34.0	5.9	520

1:4 hardwood bark/fly ash medium had a porosity greater than currently recommended for optimum root growth in container-grown plants. The hardwood bark/sand treatment, 4:1, had a porosity value of 15%, which is at the lower end of the recommended range of porosity (15%-25%) (3).

Growth

With both cotoneaster and taxus there were no differences in root or shoot growth with the exception of cotoneaster grown in 1:4 hardwood bark/fly ash medium (Table 3). Cotoneaster plants grown in this medium had 41% less shoot and root weight, respectively, when compared to the hardwood bark/sand control. Taxus root weight exhibited a similar response in the 1:4 treatment.

Fly Ash for Nursery Stock

Toward the end of the experiment, a tip chlorosis developed on all *Taxus* plants grown in a 1:2 or a 1:4 hardwood bark/fly ash medium. These visual symptoms resembled toxicity which had been encountered in similar studies with *Taxus*.

Elemental Concentration—Taxus Shoots

All taxus grown in fly ash media had greater B concentrations in the shoots than those plants grown in the hardwood/bark sand control (Table 5). Shoot B concentrations of the four fly ash media (5:1, 1:1, 1:2, and 1:4) were 22, 30, 46, and 53% greater, respectively, when compared to the hardwood bark/sand control. Plants grown in fly ash amended media had a range of 78 ppm B in the 5:1 media to 130 ppm B in the 1:4 media.

Both Fe and Mn exhibited a similar response in that both elements increased when comparing the 1:1 medium with the 5:1 medium; however, when the fly ash content of the medium increased further (1:2 or 1:4), there was a decrease in both elements.

A general trend occurred with taxus shoot P in that the P concentration decreased with increasing fly ash content of the medium; however, only with the 1:2 medium was there a difference when compared to the control treatment. Taxus shoot Mo concentration responded similarly to P, with the exception that 5:1 and 1:1 media were significantly greater than the control treatment.

Iron concentration in taxus shoots increased with fly ash ratios of 5:1 and 1:1, then decreased at greater fly ash levels. This is in contrast to cotoneaster shoot Fe concentration where Fe levels increased with increasing amounts of fly ash (Table 4). The concentration of Mn in taxus roots was greatest with the 5:1

TABLE 3.—Effects of Aggregated Fly Ash on Shoot and Root Dry Weight of 2 Container-grown Ornamentals in a Hardwood Bark Medium.

	Cotoneaster		Taxus	
Treatment (v:v)	Shoot (g)	Root (g)	Shoot (g)	Root (g)
4:1 Hardwood Bark/Sand	25.6	5.1	2.1	3.4
5:1 Hardwood Bark/Fly Ash	23.6	5.6	1.8	2.5
1:1 Hardwood Bark/Fly Ash	20.7	4.8	2.0	2.6
1:2 Hardwood Bark/Fly Ash	21.3	5.3	1.7	2.6
1:4 Hardwood Bark/Fly Ash	15.0	3.0	2.4	1.9
$LSD_{0.05}$	6.5	1.6	NS	NS

TABLE 4.—Elemental Concentration in Shoots of Container-grown Cotoneaster dammeri **'Royal Beauty' Which Were Grown in Aggregated Fly Ash Amended Media.**

Treatments (v:v)	P	K	Ca	Mg	Si	Na	Mn	Fe	B	Cu	Zn	Al	Sr	Ba	Mo
	%					ppm									
4:1 Hardwood Bark/Sand	0.26	1.3	1.5	0.25	0.19	475	168	93	62	2.8	36	23	29	12	0.9
5:1 Hardwood Bark/Fly Ash	0.23	1.5	1.4	0.24	0.20	625	138	105	62	3.5	32	19	30	12	1.2
1:1 Hardwood Bark/Fly Ash	0.20	1.4	1.5	0.26	0.20	575	167	117	73	3.5	36	14	34	14	1.2
1:2 Hardwood Bark/Fly Ash	0.18	1.4	1.5	0.31	0.26	600	139	173	65	4.0	32	20	45	16	1.4
1:4 Hardwood Bark/Fly Ash	0.18	1.4	1.5	0.27	0.26	600	143	266	62	5.0	38	22	49	16	1.4
$LSD_{0.05}$	0.03	NS	NS	0.04	0.02	NS	NS	54	NS	1.0	NS	NS	12	NS	0.3

TABLE 5.—Elemental Concentration in Shoots of Container-grown Taxus media **'Hicksii', Which Were Grown in Aggregated Fly Ash Amended Media.**

Treatments (v:v)	P	K	Ca	Mg	Si	Na	Mn	Fe	B	Cu	Zn	Al	Sr	Ba	Mo
	%					ppm									
4:1 Hardwood Bark/Sand	0.24	1.4	1.5	0.20	0.23	400	514	91	61	3.5	27	17	30	12	1.3
5:1 Hardwood Bark/Fly Ash	0.26	1.3	1.6	0.20	0.26	425	608	119	78	4.0	28	36	34	17	1.6
1:1 Hardwood Bark/Fly Ash	0.25	1.2	1.4	0.17	0.26	350	659	138	87	4.2	29	30	28	12	1.5
1:2 Hardwood Bark/Fly Ash	0.18	1.2	1.5	0.26	0.23	475	345	93	114	4.2	26	29	29	8	1.2
1:4 Hardwood Bark/Fly Ash	0.21	1.2	1.2	0.17	0.23	475	489	94	130	4.2	28	22	28	12	1.3
$LSD_{0.05}$	0.05	NS	0.18	0.04	0.02	100	116	29	15	NS	NS	NS	NS	NS	0.2

and 1:1 (v/v) fly ash treatments and lowest in the 1:2 (v/v) fly ash medium.

In both taxus and cotoneaster shoots, the decrease in P concentration with increasing fly ash content was associated with increasing concentration of a micronutrient (B in taxus, Cu and Fe in cotoneaster). In general, the elemental shoot concentrate of the control treatments of the two taxa were similar, with the possible exception of Mn and Mg. Mn concentrations in taxus shoots were approximately three times the Mn concentration in cotoneaster shoots, and Mg concentrations were approximately 20% less in taxus shoots compared to cotoneaster shoots.

Elemental Concentration—Cotoneaster Shoots

P concentration decreased while Fe and Cu concentrations increased in cotoneaster tissues with increasing volumes of fly ash in the medium (Table 4). For example, plants grown in the hardwood bark/sand control had 12, 23, 31, and 31% greater P than the 5:1, 1:1, 1:2, and 1:4 hardwood bark/fly ash treatments, respectively. Fe concentrations of the four fly ash media were 13, 26, 89, and 186% greater, respectively, when compared to the control medium. Cu concentration of the four fly ash media (5:1, 1:1, 1:2, 1:4) were 25, 25, 43, and 79% greater than the hardwood bark/sand control treatment. Mo, Si, and Sr concentrations were greatest in the 1:2 and 1:4 fly ash media. With the exception of Mg, there were no differences in the remaining elements.

DISCUSSION

This study shows that the uptake of some micronutrients may be enhanced when fly ash amended media is utilized in the production of container-grown nursery plants. In fact, when present in excessive amounts, B sensitive plants may accumulate enough B to produce B toxicity. This would agree with previous research which showed that fly ash resulted in increased Fe, Mn, and B content of *Phaseolus vulgaris* (4). Boron levels present in plants grown in fly ash were in a toxicity range for ornamental plants (3). Furthermore, current cultural practices in the nursery industry, which include the addition of numerous fertilizer additives during the production process, may preclude use of fly ash amended media. Many of the fertilizer additives contain trace amounts of B, which when coupled with B available in the medium and water, may lead to B toxicity.

Preliminary research by the authors has shown that several species can be grown satisfactorily in fly ash amended media for one season. Pyracantha, cotoneaster, and ligustrum were successfully grown in fly ash amended media (unpublished data). However, the limited duration of these experiments and the wide variation among woody plants in response to B would preclude any recommendation for the use of fly ash in a container-growing medium.

Evergreen plants are more sensitive to B toxicity than deciduous taxa because B accumulates in the leaves where it is immobile. With deciduous crops, these leaves may abscise before B becomes a problem, while with evergreens, B continues to accumulate in the most recent growth. These physiological differences in the growth of deciduous and evergreen taxa may permit the satisfactory use of fly ash in the production of container-grown deciduous species.

With deciduous plants, fly ash may be desirable where adequate porosity is unavailable in the medium or where increased bulk density is needed.

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Fertilizing Trees in the Landscape: A 9-Year Evaluation

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ABSTRACT

The growth of *Tilia cordata, Malus* 'Snowdrift', and *Acer saccharum* 'Monumentale' was not affected by fertilizer placement. Significant growth increases were observed from drill hole treatments without fertilizer, with *Tilia* indicating a direct benefit from aeration in poorly drained soils. Nearly all nitrogen treatments resulted in trunk caliper and diameter of branch spread increases, with the 6 and 9 lb N/1000 ft² treatments every 3 years the most effective.

INTRODUCTION

Many, if not the majority of, trees planted around newly constructed residences and commercial buildings are located in soils which are less than desirable for plant growth. These sites are often composed of subsoil, low in organic matter, heavily compacted, and typically poorly drained. For these reasons, trees in the landscape must be fertilized regularly to survive the poor soils. A well-fertilized tree will also be more resistant to insect and disease problems and more tolerant of winter conditions.

Traditionally, fertilizer recommendations for trees have been based on trunk caliper. However, in recent literature the basis has changed to soil surface area (1, 3, 4). Nitrogen research and subsequent recommendations indicate that optimum tree growth will result from the application of from 2-3 lb N/1000 ft²/yr to 6 lb N/1000 ft² (5, 6, 9, 10). Tree growth is more directly related to fertilizer rate than to differences in fertilizer placement (2, 7).

The objectives of this research were to evaluate tree growth, in sites similar to many home landscapes, as a function of four nitrogen levels and two methods of placement.

MATERIALS AND METHODS

This investigation was conducted in the USDA Nursery Crops Research Nursery in Delaware, Ohio. The soils were poorly drained Blount and Morley silt and Pewamo silty clay loam with a pH of 6.9.

The tree species, planted as branched whips in April 1969, included *Tilia cordata* 'Select', Improved Littleleaf Linden; *Malus* 'Snowdrift', Snowdrift Flowering Crabapple; and *Acer saccharum* 'Monumentale', Sentry Sugar Maple. The trees were grown in sod culture and mowed as needed.

All trees received 6 lb of actual phosphorus and potassium per 1000 ft² in May 1971, April 1974, and 1977. The nitrogen, in the form of ammonium nitrate, was applied at the same time at either 0, 3, 6, or 9 lb N/1000 ft². One-half of the treated trees received nitrogen as a surface application while the remainder were treated via a drill hole application. The 20 holes per tree, drilled with a 2-inch power auger 12 inches deep, were spaced in two concentric rings with a 100 ft² area around each tree.

In the drill hole treatments, the fertilizer was mixed with calcined clay marketed as Sta-red-bits. One treatment consisted of a drill hole treatment filled with calcined clay without fertilizer to evaluate the effects from aeration alone.

The study was conducted utilizing a randomized block design with three trees per treatment and four replications.

RESULTS AND DISCUSSION

Providing aeration to the root system has been recommended as a means of improving tree growth and this was observed in this study (Table 1) with *Tilia* but not *Malus* or *Acer*.

All treatments resulted in significant growth increases of *Tilia* when compared to the control trees which received no nitrogen. However, there were no significant differences after 9 years between 3, 6 or 9 lb N/1000 ft² treatments or between drill hole or surface placements. Average caliper growth was larger in *Tilia* than *Malus* or *Acer*. Evidence of trunk splitting observed in 1974 (8) in control trees, most likely as a result of nitrogen deficiency and excess moisture, was still evident on many trees.

The difference of trunk caliper of *Malus* was pronounced from fertilizer treatments after 3 and 6 years but not after 9 years (Table 2). However, trees in the 6 and 9 lb N/1000 ft² treatments were significantly larger than control trees in both the drill hole and surface placements. There were no differences in growth between the 6 and 9 lb N treatments, indicating that 6 lb N would be satisfactory as a treatment every 3 years.

In general, the average caliper growth of Sentry sugar maple was less than either of the other two species. The trend toward the greatest growth in the 6 and 9 lb N treatments was similar in *Acer* to the other species (Table 3) after 6 years but only the 6 lb drill hole treatment and 9 lb surface treatment were significant after 9 years.

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TABLE 1.—Average Caliper Growth in Inches of Littleleaf Linden After 3, 6, and 9 Years of Nitrogen Fertilizer Treatment.

Treatment	3 Years	6 Years	9 Years	Av./yr
Control, No Holes, No N	2.0*	3.03 a†	4.84 b	0.54
Holes Only plus Calcined Clay	2.9	4.33 b	6.38 a	0.71
3 lb N Drill Hole	3.0	4.58 bc	6.71 a	0.75
6 lb N Drill Hole	3.0	4.55 bc	6.83 a	0.76
9 lb N Drill Hole	3.0	4.80 cd	7.03 a	0.78
3 lb N Surface	3.0	4.78 bcd	6.90 a	0.76
6 lb N Surface	3.2	4.90 cd	6.88 a	0.76
9 lb N Surface	3.1	5.08 d	7.49 a	0.83

*Each figure represents the average of 12 trees measured 1 foot from the soil line.
†Letters followed by dissimilar letters within columns are significantly different at the 5% level.

TABLE 2.—Average Caliper Growth in Inches of Snowdrift Flowering Crabapple After 3, 6, and 9 Years of Nitrogen Fertilizer Treatment.

Treatment	3 Years	6 Years	9 Years	Av./yr
Control, No Holes, No N	2.7*	3.40 a†	5.19 c	0.58
Holes Only plus Calcined Clay	3.0	4.30 b	5.53 abc	0.61
3 lb N Drill Hole	2.8	4.35 b	5.28 bc	0.59
6 lb N Drill Hole	3.1	4.83 cd	6.23 ab	0.69
9 lb N Drill Hole	3.1	4.85 cd	6.23 ab	0.69
3 lb N Surface	2.8	4.50 bc	5.40 abc	0.60
6 lb N Surface	3.3	5.13 d	6.39 a	0.71
9 lb N Surface	3.1	4.85 cd	6.17 ab	0.69

*Each figure represents the average of 12 trees measured 1 foot from the soil line.
†Letters followed by dissimilar letters within columns are significantly different at the 5% level.

TABLE 3.—Average Caliper Growth in Inches of Sentry Sugar Maple After 3, 6, and 9 Years of Nitrogen Fertilizer Treatment.

Treatment	3 Years	6 Years	9 Years	Av./yr
Control, No Holes, No N	2.5*	3.38 a†	4.71 bc	0.52
Holes Only plus Calcined Clay	2.8	3.50 ab	4.56 c	0.51
3 lb N Drill Hole	2.9	4.00 cd	5.46 abc	0.61
6 lb N Drill Hole	3.2	4.50 e	6.11 a	0.68
9 lb N Drill Hole	2.9	3.95 bcd	5.50 ab	0.61
3 lb N Surface	2.8	3.53 ab	4.93 bc	0.55
6 lb N Surface	2.9	3.88 bc	5.36 abc	0.60
9 lb N Surface	3.1	4.35 cd	5.98 a	0.66

*Each figure represents the average of 12 trees measured 1 foot from the soil line.
†Letters followed by dissimilar letters within columns are significantly different at the 5% level.

TABLE 4.—Diameter of Branch Spread Following 9 Years of Nitrogen Fertilizer Treatment.

Treatment	Littleleaf Linden	Snowdrift Flowering Crabapple	Sentry Sugar Maple
		(Diameter in Feet)	
Control, No Holes, No N	9.6*	11.6	9.9
Holes Only plus Calcined Clay	12.2	12.6	9.4
3 lb N Drill Hole	12.9	12.7	11.3
6 lb N Drill Hole	13.5	14.3	12.3
9 lb N Drill Hole	13.8	13.7	11.5
3 lb N Surface	13.6	12.9	10.4
6 lb N Surface	13.8	14.7	11.1
9 lb N Surface	15.1	14.6	12.0

*Each figure represents an average of 12 trees.

There were no growth differences in any of the genera between drill hole and surface treatments.

The diameter of branch spread as a result of fertilizer treatments was as indicative of growth differences as caliper growth (Table 4). Again, little differences in diameter of branch spread were evident between fertilizer placement treatments. The 6 and 9 lb N/1000 ft^2 rates resulted in the largest diameter with all three genera.

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Effects of Nitrogen Fertilization on *Acer rubrum* 'Red Sunset' Grown in Containers

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ABSTRACT

The response of container grown *Acer rubrum* 'Red Sunset' to three nitrogen levels applied from June to September was studied. Trees fertilized at 150 and 300 ppm N exhibited a second growth flush. Tissue analysis of mature and immature leaves indicated that trees fertilized with 300 ppm N contained higher N concentrations. Fall color of plants fertilized with 50 ppm N was fully developed 3 weeks before plants that received 300 ppm N. Subsequent growth the following spring was significantly greater on trees fertilized with 300 ppm N.

INTRODUCTION

The production of container-grown nursery stock has steadily increased since the practice was started in the 1950's. Until recently, most container-grown plants were evergreens or deciduous shrubs. However, in the past few years, several nurserymen have expressed an interest in the feasibility of growing quality shade trees as container plants. The freight expense of shipping larger caliper shade trees as balled and burlapped plants and the increasing value of nursery land could result in a switch to container production. This may be particularly true of red maple cultivars which can now be grown on their own roots (4).

Fertilizer recommendations for field grown shade trees are available; however, there is limited information on fertilization of container-grown shade trees. The purpose of this study was to determine the effects of three nitrogen rates on growth, fall color, leaf retention, and mineral composition of a red maple cultivar grown in a container.

MATERIALS AND METHODS

Bare root 1-year-old budded whips of 'Red Sunset' red maple were potted into 20 liter (5 gal) plastic containers in a medium of 4:1 (by volume) composted pinebark/sand on May 16, 1979. Plants were fertilized with NH_4NO_3 at the rates of 50, 150, and 300 ppm N once weekly through August. These trees were grown in the container nursery at The Ohio State University, Columbus, and were arranged in a completely randomized design with four replications of three plants each.

On Sept. 24, 1979, the number and length of newly flushed shoots were determined. Separate samples of recently mature and immature leaves were collected and analyzed for mineral element composition (5). On Oct. 15, 22, 29, Nov. 5 and 8, the number of leaves per tree were determined and recently mature leaf samples were collected on each date. These samples were frozen until the leaves could be extracted for colorimetric evaluation (8). A Bausch & Lomb Spectronic 20 colorimeter was used to obtain a spectral scan on red, intermediate red-green, and green leaves. Peak absorption occurs at 425 nm for red colored leaves and 665 nm for green colored leaves. All samples were measured at 425 and 665 nm to indicate leaf color differences. The leaves also were visually evaluated for color using a color dictionary (3). This visual rating was then matched to the spectral difference obtained by Red_{425} minus $Green_{665}$.

After evaluation of the trees during the fall, they were stored in a single layer polyhouse during the winter. During this period, no fertilizer was applied. On June 5, 1980, the lengths of the five longest new shoots were measured and recently expanded leaves were collected for mineral element composition.

RESULTS AND DISCUSSION

The data received in 1979 illustrated that plants which received 150 and 300 ppm N weekly produced a second growth flush while those receiving 50 ppm N did not (Table 1). Plants grown at 150 and 300 ppm N had four and five new shoots, respectively, per tree. The plant height was not increased, as the new growth occurred primarily on lateral branches. These data agree with that previously reported for holly which showed that higher N rates produced more frequent growth flushes (1).

Shoot length measurements taken in June 1980 followed the same trend as those taken the previous fall (Table 2). Trees that received 300 ppm N produced a significantly longer flush of growth than those trees receiving 50 ppm N. Although the growth difference between plants receiving 150 and 300 ppm N was not significant, the difference was larger than observed in the fall. This difference may become greater as the N treatments continue, as evidenced by

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TABLE 1.—Effects of Three Nitrogen Levels on the Growth of Acer rubrum **'Red Sunset'.**

Nitrogen (ppm)	No. New Shoots (Second Flush 1979)	Shoot Length (cm) (Second Flush 1979)	Shoot Length (cm)* (First Flush 1980)
50	0	0	11.2
150	4	5	14.6
300	5	5	17.7
LSD 5%	0.85	1.1	6.0

*Shoot length is an average of five longest shoots.

comparing the difference in N content of the leaves between the fall and spring at 150 and 300 ppm N (Table 2).

Applications of 300 ppm N resulted in higher tissue N in both mature and immature leaves (Table 2). This was particularly apparent with the data collected in June 1980. According to recent information (2), levels of 1.3% and 1.5% are low N levels for optimum growth of woody ornamentals. A value of 2.6% N would fall in the sufficient range of most woody ornamentals. The lack of differences in tissue N concentration between leaves of plants receiving 50 and 150 ppm N (fall data) was probably due to the dilution of N as a result of transport to new growth in plants receiving 150 ppm N. Plants treated with 50 ppm produced no new growth.

These data point out a general weakness of foliar analysis. If the recently mature leaves had been sampled without noting that new growth had occurred, it may have appeared that the two treatments, 50 and 150 ppm N, were identical in tissue N. However, previous data (7, 9) show that the tissue N of recently matured leaves is decreased when new growth occurs.

TABLE 3.—Effects of Three Nitrogen Levels on Leaf Color of Acer rubrum **'Red Sunset'.**

	Leaf Color*		
	N Level		
Date	50 ppm	150 ppm	300 ppm
Oct. 15	0.18	0.22	0.32
Oct. 22	0.09	0.19	0.22
Oct. 29	0.12	0.17	0.24
Nov. 5	0.09	0.10	0.14
Nov. 8	0.05	0.08	0.12
LSD 5% (rows and columns) = 0.06			

*Value determined by subtracting absorbance readings at 625 nm from absorbance readings at 425 nm. The values were equated to color by determining leaf color with a color dictionary. Values less than 0.14 indicate 100% of the sample leaves were red. Values between 0.15 to 0.24 indicate predominant leaf color to be intermediate (reddish-green or greenish-red); the lower values indicate red and the higher values green. Values above 0.24 indicate 100% of the sample leaves were green.

TABLE 2.—Effects of Three Nitrogen Levels on Mineral Composition of Acer rubrum **'Red Sunset'.**

	Nutrient Concentration (Dry Wt Basis)						
N (ppm)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Fe (ppm)
			Mature Leaves (1979)				
50	1.8	0.10	0.59	1.06	0.49	331	236
150	1.8	0.10	0.68	0.88	0.43	310	206
300	2.1	0.09	0.60	1.08	0.54	263	243
LSD 5%	0.10	NS	0.03	NS	0.05	NS	NS
			Immature Leaves (1979)				
50							
150	1.2	0.14	1.22	0.72	0.20	29	155
300	1.7	0.10	0.69	0.96	0.27	29	155
LSD 5%	0.24	0.01	0.10	0.12	0.03	NS	NS
			Mature Leaves (1980)				
50	1.3	0.22	0.72	0.65	0.31	63	46
150	1.5	0.25	0.70	0.74	0.36	66	47
300	2.6	0.43	0.80	0.92	0.41	64	50
LSD 5%	0.25	0.08	NS	0.23	0.07	NS	NS

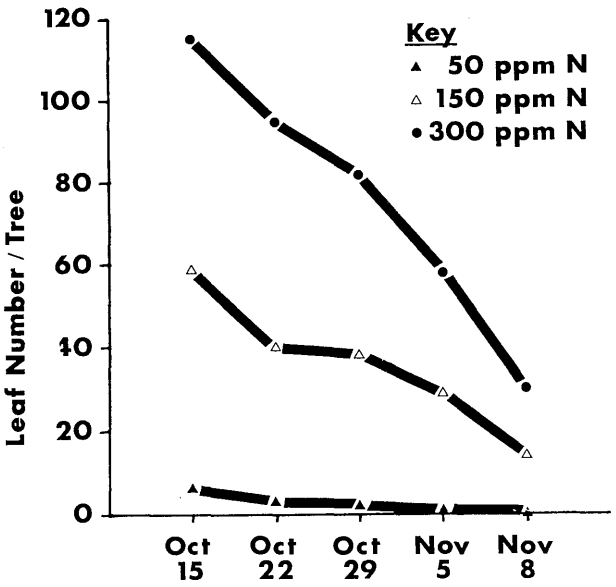

FIG. 1.—Effects of three nitrogen levels on leaf defoliation of Acer rubrum **'Red Sunset'.**

Earliest fall color and leaf defoliation occurred when 'Red Sunset' red maple was grown under low N (50 ppm N) (Table 3 and Fig. 1). Fall color on trees grown at 50 ppm N was fully developed by Oct. 22 (various shades of red as defined by the color dictionary), while the red color on trees grown at 150 and 300 ppm N was not fully developed until Nov. 5. With trees treated with 150 or 300 ppm N, defoliation began prior to the development of fall color (Fig. 1). Trees grown at 300 ppm N retained their leaves about 3 weeks longer than plants grown at 50 ppm N.

These results indicate that higher N rates increased growth, delayed fall color, and produced longer leaf retention. Low N (50 ppm) resulted in one annual growth flush, early fall color, and defoliation. Growth data and tissue analysis indicate that in this study 300 ppm N was the best rate.

Additional research is needed to determine the suitability of shade trees for container growing. Future research will investigate the effectiveness of higher N rates and a comparison of container-grown vs. field-grown 'Red Sunset' red maple of comparable age.

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Shoot Tip Culture of *Amelanchier laevis*

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ABSTRACT

Shoot tip cultures of *Amelanchier laevis* proliferate rapidly *in vitro* on a Murashige-Skoog medium containing 0.1 mg/1 NAA and 2.5 mg/1 BA. An average 40-fold multiplication after 4 months was achieved. The shoots could be removed as cuttings and placed on a one-fourth strength Murashige-Skoog medium containing 0.1 mg/1 IBA where rooting could be observed in as little as eight days. This system responds to the *in vitro* environment in a fashion similar to other trees of the Rosaceae which have been reported in the literature.

INTRODUCTION

Many trees in the family Rosaceae have been propagated by tissue culture. Primary attention to date has focused upon those grown commercially for fruit. Cherry, plum, peach, almond, and both scion and rootstock cultivars of apple have been multiplied *in vitro* (1, 2, 3, 4, 6). Established cultures of the plum rootstock 'Pixy' and the cherry rootstock 'F 12/1' have achieved a hundred-fold multiplication in 8 months (2). Cox's Orange Pippin apple explants produced 10 shoots per culture 6 weeks after subculturing (1). Shoot tip cultures of the rootstock clone M26 each produced between 20 and 42 shoots after 18 weeks in culture (3).

Shoots which had been produced in tissue culture were stimulated to form roots by transferral to a culture medium similar to the shoot multiplication medium but lacking the cytokinin. This medium contained 0.1 mg/1 IBA (indolebutyric acid) which stimulated rooting of up to 97% of the M26 shoot tip cuttings within 6 weeks (3). This technique has also been successfully applied in the rooting of cultured shoot tips of five apple scion cultivars (4) and a similar technique was described for tissue cultured almond clones (6).

The research described in this article represents the application of these tissue culture techniques to the plant *Amelanchier laevis*. *Amelanchier* is a deciduous small tree in the Rosaceae, and is similar to the apples, cherries, and plums in many morphological and physiological respects. The objectives of the current investigation were to describe a system for the *in vitro* propagation of *Amelanchier*, determine the rate of multiplication, and devise a system for rooting the cuttings which would be produced.

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MATERIALS AND METHODS

Shoot tips of *Amelanchier laevis* were taken during the first growth flush on May 1, 1980, in Columbus, Ohio. Expanded leaves were removed and the tips were sterilized by immersion in 10% Clorox for 20 minutes. Following rinsing in sterile distilled water, the basipetal end of the shoot tip was removed and the resulting 1 cm apical portion was placed on culture medium.

The culture medium contained the inorganic salts and organic components according to Murashige and Skoog (5). Cultures were initiated on agar gelled medium in 30 ml French square bottles containing 1 mg/1 benzyladenine (BA). Following 10 weeks of growth on the initial medium, shoot cultures were transferred to 125 ml bottles containing a similar medium except the growth regulator concentration was 0.1 mg/1 napthaleneacetic acid (NAA) and 2.5 mg/1 BA. Cultures are currently being maintained on the medium containing 0.1 mg/1 NAA and 2.5 mg/1 BA in 500 ml glass jars capped with glass petri dishes and sealed with saran wrap. All cultures were grown at 26° C under 500 foot candles of warm white fluorescent light with a daylength of 16 hours.

FIG. 1.—Mass of shoots which have proliferated from a single shoot tip of Amelanchier **after 4 months in tissue culture.**

FIG. 2.—Rapid multiplication of Amelanchier **occurs due to active growth of axillary shoots. Actively growing lateral shoots are indicated by the arrows.**

Rooting experiments are being conducted using one-fourth strength Murashige-Skoog medium solidified with agar and containing 0.1 mg/l indolebutyric acid (IBA). The 500 ml jars are used for the rooting phase.

RESULTS AND DISCUSSION

Shoot tip cultures of *Amelanchier laevis* were induced to proliferate in tissue culture (Fig. 1). Multiple shoots are seen to arise from a basal mass, which actually represents small, unexpanded shoots rather than callus. Little if any callus has been observed in any of the cultures examined to date.

Shoot multiplication appears to proceed primarily by lateral shoot growth, although formation of adventitious shoots cannot be ruled out. When cultures are examined closely, the active growth of lateral shoots can be observed (Fig. 2, arrows). In some cases, lateral shoots have been observed in active growth as close as one or two expanded internodes distance from the shoot tip. The conditions of the tissue culture environment thus appear to circumvent apical dominance and result in a mass of shoots each producing more shoots.

Cultures resulting from seven individual shoot tips have been sacrificed to date either as a result of contamination or in order to conduct rooting experiments. These have been in culture for a total of 4 months. A detailed count revealed more than 280 shoot tips present in the seven cultures. The mass from one shoot tip contained 105 individual shoot tips, while the remainder of the cultures contained fewer shoots.

Those shoot tips which had elongated to between 1.5 and 2.0 cm in length were used in subsequent rooting experiments (Fig. 3). Of the 280 shoots produced in the seven cultures, 110 of these had elongated sufficiently to be deemed suitable for rooting experiments. Rooting was attempted by placing the shoot tips in one-fourth strength Murashige and Skoog medium containing 0.1 mg/l IBA. The culture vessels were 500 ml glass jars with glass petri dish covers so that the lighting for the cultures was maximized. Roots at least 1 mm in length were observed on one shoot tip cutting after only 8 days in the rooting medium. Eight of the 40 shoots in the experiment had at least one root by 14 days. Further experiments are currently in progress to increase the percentage of cuttings which root.

The ability to mass propagate *Amelanchier* through tissue culture adds further evidence that plants within the Rosaceae should respond similarly to the *in vitro* environment. The conditions described herein are very similar to those described for apples (1, 3, 4) and plums and cherries (2). The rate at which multiplication occurs (even considering the very slow initial phase), approximately a 40-fold increase in 4 months, suggests that propagation via tissue culture could be a commercially feasible method for *Amelanchier* provided a suitable system for growing on the

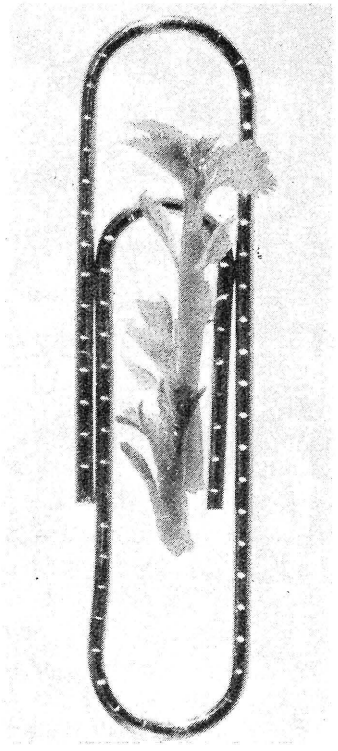

FIG. 3.—Shoots were removed for rooting when they exceeded 1.5 cm in length. This shoot tip cutting from tissue culture was photographed with a 3 cm paper clip for scale comparison.

rooted plantlets were developed. Improvement of the rooting methodology and the development of a system for the accelerated production of *Amelanchier* from tissue cultured plantlets are the goals of the next phase of this research.

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Effects of Cutting Dates and Rates of IBA on the Rooting of Four *Tilia* Taxa

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ABSTRACT

Softwood and semi-hardwood cuttings of four *Tilia* taxa were taken at different times and treated with high concentrations of IBA. Rooting-response varied with taxa and cutting date. Rooting in American linden cuttings was maximum when taken on May 19 and June 1. Cuttings of littleleaf linden did not differ significantly in rooting when taken on May 19, June 22, or July 13, but rooting was significantly less with August 3 cuttings. Crimean linden cuttings did not root. All 'Redmond' linden cuttings taken on May 19 or June 22 rooted. A 5-second basal dip of IBA significantly stimulated rooting, especially in the range of 20,000 ppm.

INTRODUCTION

The landscape qualities of various species and cultivars of *Tilia* (linden) have been well described (2, 3, 4, 8). Evaluating urban trees, Chapin and Kozel (3) rated several cultivars of littleleaf linden *(Tilia cordata)* as excellent for foliage density and color, branch and crotch development, and overall growth rate, all of which make lindens popular with the gardening public. *Tilia* is also tolerant to pollution and adapts to poor soil (4, 8).

Commercially, lindens have been propagated by field budding or grafting. However, these methods present problems with incompatibility, high production costs, and rootstock suckering. Seed propagation is complex and often unreliable (4). Average germination for American linden has been reported as 31% and for littleleaf linden it was 33% (2).

Attempts to root *Tilia* from hardwood cuttings have only been partially successful (1, 5, 7). Recent research interest has been directed toward cutting propagation of linden. Because little information is available on cutting propagation of *Tilia* from mature trees, an experiment was designed to study the feasibility of rooting cuttings taken from mature trees of four *Tilia* taxa. The effects of cutting dates and IBA treatments were also determined.

MATERIALS AND METHODS

Cuttings were removed from mature trees of four *Tilia* taxa which were 20-40 years old. The taxa included *T. americana* (American), *T. cordata* (littleleaf, *T.* x *euchlora* (Crimean), and *T.* x *euchlora* 'Redmond'. Six-inch cuttings were taken at random from terminal growth throughout the trees. Cutting dates were May 19, June 1, June 22, July 13, and August 3, the last date being omitted for American linden.

Cuttings were treated with 0, 10,000, 20,000, 25,000, 30,000, and 35,000 ppm IBA dissolved in 50% ethanol. Fifty percent ethanol served as the control. Cuttings were dipped in IBA for 5 seconds and then placed in a 7:3 perlite:peat medium.

Intermittent mist was applied for 6 seconds every 3 minutes and rooting evaluations were made after 30 days. Rooting percentage and quality rank were taken on three replications, consisting of seven cuttings each. Rooting percentage was the percentage of cuttings that initiated roots. Quality rank was based on the number of roots per cutting (6).

Rank	Number of Roots
1	1-5
2	6-10
3	11-15
4	16-20
5	21-25
6	26-30
7	31-35
8	> 35

RESULTS AND DISCUSSION

Tilia americana: Cutting date did not significantly influence rooting percentage of American linden (Table 1). Cuttings taken on June 2 had the highest average rooting percentage, although not significantly different than other dates. Root qualities of cuttings taken on May 19 or June 1 were better than for cuttings taken later in the season. Data for American linden (Table 1) show that rooting percentage and quality rank were increased by IBA treatments. The number of roots of *T. americana* cuttings taken on June 1, June 22, and July 13 increased as IBA concentration was increased, except that the highest IBA concentration decreased values for June 1 and 22.

Tilia cordata: Rooting percentage and quality rank were higher for cuttings taken on May 19, June 22, and July 13 than for August 3. IBA treatments did not affect rooting percentage but did increase root quality. For example, 81% of cuttings taken on May 19 which received no IBA rooted, but the quality rank was only 1.3 (approximately seven roots). However,

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TABLE 1.—Effects of Cutting Dates and IBA Treatments on Rooting Percentage and Quality Rank of Tilia americana **Cuttings. Mean Separation Within Rows and Columns by Duncan's Multiple Range Test, 5% Level.**

Trt. x 1000 mg l^{-1} IBA	Rooting Percent					Quality Rank				
	May 19	June 1	June 22	July 13	Trt. Av.	May 19	June 1	June 22	July 13	Trt. Av.
0	0 c	10 k	52 b	19 k	20 g	XX*	1.0 m	1.6 b	1.0 m	1.2 g
10	81 ab	71 j	61 ab	71 j	71 f	3.6 c	4.3 k	2.9 b	1.8 m	3.1 f
20	100 a	100 j	85 ab	76 j	90 e	7.0 ab	6.0 jk	4.8 a	5.0 k	5.7 e
25	76 ab	67 j	81 ab	81 j	76 ef	7.8 a	5.4 jk	5.6 a	5.3 jk	6.0 e
30	95 ab	95 j	95 a	76 j	90 e	6.8 ab	6.7 j	5.7 a	5.8 jk	6.2 e
35	61 b	91 j	71 ab	85 j	77 ef	5.6 b	6.3 j	5.3 a	6.8 j	6.0 e
Av.	69 p	72 p	75 p	68 p	71	6.2 p	5.4 p	4.5 q	4.5 q	5.1

**XX=No assigned value due to no rooting.

the cuttings that were treated with 10,000 ppm IBA rooted at 61% but had a quality rank of 7.3. This comparison illustrates the problem involved in using rooting percentage as the only measure of rooting potential.

***Tilia* x *euchlora* 'Redmond':** Redmond linden had the highest rooting percentage among taxa tested (Table 3). Except for the August 3 cutting date, average rooting exceeded 88%, with rooting exceptionally good on IBA treated cuttings taken on May 19. Rooting percentages were 100 for at least one IBA treatment on May 19, June 22, and August 3, and 95% for July 13. Cuttings taken on May 19, June 22, and July 13 had quality ranks of 6.2 to 7.8. After May 19, the root quality value decreased with time. Lower concentrations of IBA were sufficient for high rooting percentage earlier in the year, but increased amounts of IBA were needed as the season progressed; to obtain 100% rooting in August, 35,000 ppm IBA were required.

Tilia x euchlora: Cuttings of Crimean linden had almost no rooting regardless of date of excision,

TABLE 2.—Effects of Cutting Date and IBA Treatments on Rooting Percentage and Quality Rank of Tilia cordata **Cuttings. Mean Separation Within Rows and Columns by Duncan's Multiple Range Test, 5% Level.**

Trt. x 1000 mg l^{-1} IBA	Rooting Percent					Quality Rank				
	May 19	June 22	July 13	Aug. 3	Trt. Av.	May 19	June 22	July 13	Aug. 3	Trt. Av.
0	81 ab	71 j	86 a	43 j	70 e	1.3 b	2.0 m	1.7 b	1.3 km	1.6 f
10	61 ab	71 j	100 a	43 j	69 e	7.3 a	5.4 jk	4.9 a	2.6 jk	5.0 e
20	61 ab	61 j	85 a	52 j	65 e	6.6 a	4.0 km	5.6 a	5.0 j	5.3 e
25	85 a	61 j	67 a	52 j	67 e	6.2 a	6.3 jk	6.2 a	3.0 jk	5.4 e
30	48 b	76 j	85 a	43 j	63 e	6.7 a	6.7 a	4.6 a	4.1 j	5.5 e
35	91 a	43 j	71 a	24 j	57 e	5.8 a	6.8 j	5.9 a	3.3 jk	5.5 e
Av.	71 p	64 p	83 p	43 p	65	5.7 p	5.1 p	4.8 p	3.1 q	4.7

TABLE 3.—Effects of Cutting Date and IBA Treatments on Rooting Percentage and Quality Rank of Tilia x euchlora **'Redmond' Cuttings. Mean Separation Within Rows and Columns by Duncan's Multiple Range Test, 5% Level.**

Trt. x 1000 mg l^{-1} IBA	Rooting Percent					Quality Rank				
	May 19	June 22	July 13	Aug. 3	Trt. Av.	May 19	June 22	July 13	Aug. 3	Trt. Av.
0	38 b	91 j	85 a	29 m	61 g	1.0 b	2.5 m	1.4 c	1.1 m	1.5 h
10	100 a	100 j	95 a	24 m	80 f	7.3 a	4.6 k	3.9 c	1.6 m	4.6 g
20	100 a	100 j	91 a	71 k	90 e	7.4 a	6.8 j	4.5 bc	4.1 jk	5.7 f
25	100 a	95 j	86 a	71 k	88 ef	7.6 a	7.4 j	5.9 a	1.5 jk	6.1 lef
30	100 a	95 j	86 a	67 k	87 ef	7.8 a	7.1 j	6.2 a	4.9 j	6.5 e
35	100 a	100 j	86 a	100 j	96 e	7.7 a	7.1 j	5.4 ab	1.4 k	5.9 ef
Av.	90 p	97 p	88 p	60 q	84	6.5 p	5.9 p	4.6 q	1.1 r	5.1

and the best rooting was with 0 and low concentrations of IBA. Highest rooting percentages, 29 and 24, came from June cuttings treated with 0 or 10,000 ppm IBA, respectively. Quality ranks of rooted cuttings averaged 2 or lower.

Time to root in this experiment (30 days) was considerably shorter than that reported by previous research by Peterson *et al.* (5). Their American linden cuttings required 91 days in the propagation bench, probably because they used "rootone" powder instead of high IBA treatments. The 30-day rooting period means less tie-up of bench space for the nursery propagator.

This experiment also gave exceptionally high rooting percentage compared with those previously reported (5). For example, Redmond linden cuttings taken on May 19 produced 100% rooting at all IBA treatments (Table 3). Among June 22 cuttings, those treated with 10,000, 20,000, and 35,000 ppm IBA each resulted in 100% rooting. Even with supposedly easier-to-root stump sprout cuttings, Peterson *et al.* (5) obtained only 22-47% rooting.

These data indicate that softwood and semi-hardwood cuttings taken from mature linden trees can be induced to initiate roots after applications of high concentrations of IBA, but optimum cutting date and IBA concentration vary with taxa. Rooting quality was best when cuttings were taken in May to mid-June. Later dates required more IBA for comparable results.

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Variation in Wound-Closure Rates Among *Acer rubrum* Cultivars

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ABSTRACT

Twelve red maple cultivars and the species *Acer rubrum* were evaluated for relative wound-closure rate. Four trees of each cultivar received four 10 mm wounds per tree on May 18, 1980. Wound-closure 4 weeks after wounding showed a significant cultivar effect. *Acer rubrum* 'Autumn Glory' exhibited the most rapid closure and *Acer rubrum* 'October Glory' had the slowest rate of closure during the 1980 growing season.

INTRODUCTION

Adaptability of a tree to the urban landscape often hinges on its inherent ability to rapidly and effectively cope with the myriad of wounds incurred in such an environment. Pruning, systemic injections, storms, and human abuse all take their toll. Wound response has been shown to be quite variable and probably is an expression of the tree's genetic potential (1, 9). Municipal arborists and nurserymen are currently quite concerned with such characteristics (1, 2, 3).

Several studies have already shown traditional wound dressings such as asphalt paints, shellac, and latex materials to be of essentially no value in speeding the wound-closure process (5, 6, 7, 8, 9). Black plastic has shown some potential for increasing closure rate and degree of compartmentalization as a consequence of etiolation, humidity, temperature, and air exchange properties (4, 11).

Neely has postulated that wound-closure rate is entirely dependent upon increase in caliper or radial growth regardless of species (8). Others feel that if genetics modify the response to wounds, it would be possible to select trees for use in cities which would close and compartmentalize wounds rapidly (1, 9). Maintenance and replacement costs would thus be reduced and environmental quality would be improved.

MATERIALS AND METHODS

A total of 52 red maples *(Acer rubrum)* in the Shade Tree Evaluation Plot at the Ohio Agricultural Research and Development Center were used in this study. This included four of each cultivar including the species as listed in Table 1. Trees range in age from 9 years for *Acer rubrum* 'Doric' to 15 years for most of the remaining cultivars.

TABLE 1.—Mean Closure by Cultivar of Acer rubrum **4 Weeks After Receiving a 10 mm Wound.**

Cultivar	Closure (mm)*
Autumn Glory	7.8
Red Sunset	6.8
Doric	6.5
Schlesinger	6.4
Autumn Flame	6.4
Tilford	5.9
Columnare	5.2
Scanlon	4.9
Species	4.8
Armstrong	4.4
Bowhall	4.4
Gerling	4.4
October Glory	2.6
Av.	5.4
$LSD_{0.05}$	0.9

*Mean closure in millimeters based on an average of 16 wounds per cultivar or species. Closure = 10 mm original wound minus remaining opening. A closure of 10 would be completely closed.

On May 8, 1980, trees were wounded in each of the four compass directions at a height of approximately 1.5 meters. A wound consisted of a 10 mm diameter x 10 mm deep hole drilled into the tree using

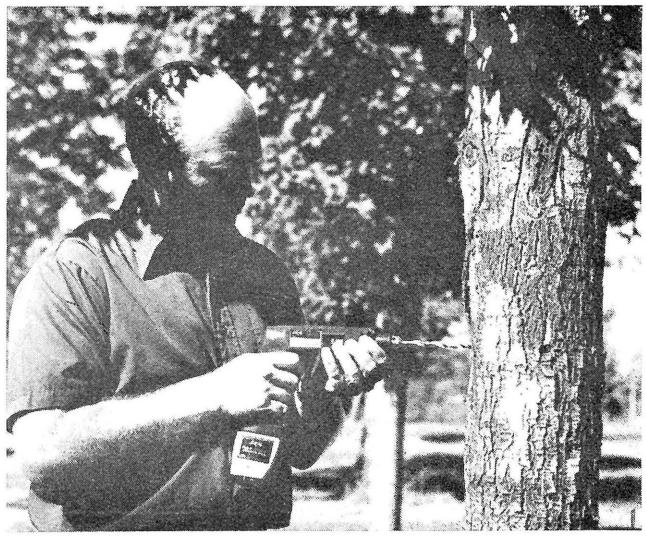

FIG. 1.—A rechargeable electric drill was used to create the 1 cm diameter wound. Twist drills as shown produce less cambial die-back than other types of drill bits.

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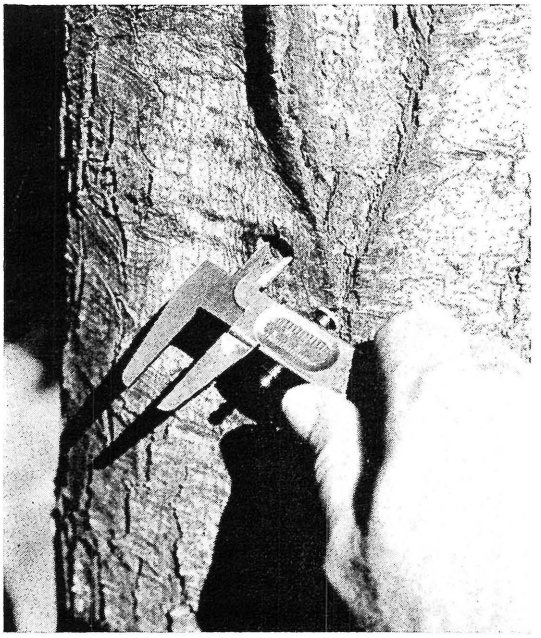

FIG. 2.—Width of wound opening was measured with an inside-reading micrometer.

a portable rechargeable electric drill (Fig. 1). A length of black plastic tape was then placed completely around the trunk in order to cover the four wounds.

Width of opening for each wound was determined and recorded weekly with the aid of an inside-reading micrometer (Fig. 2).

RESULTS AND DISCUSSION

Wound-closure data collected the fourth week following wounding was compiled and analyzed to determine effects due to cultivar and direction. The effects due to direction were judged to be of no overall practical significance. There was, however, a slightly poorer overall mean rate of closure for west-facing

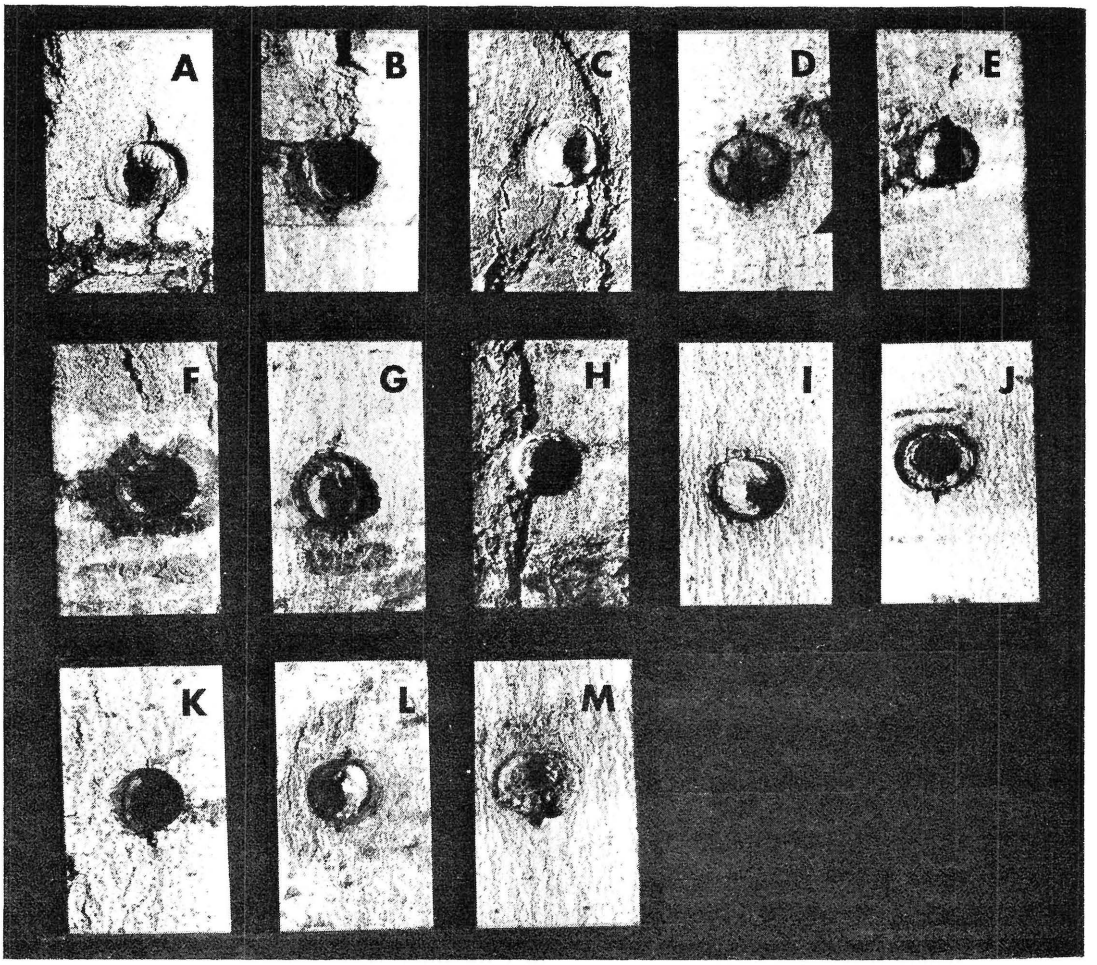

FIG. 3.—Typical closure patterns of the 13 cultivars of Acer rubrum **at 4 weeks. All wounds are approximately actual size. Cultivar designations are as follows: A—species, B—Armstrong, C—Autumn Flame, D—Autumn Glory, E—Bowhall, F—Columnare, G—Gerling, H—October Glory, I—Red Sunset, J—Scanlon, K—Schlesinger, L—Tilford, and M—Doric.**

wounds, which was especially pronounced for the cultivar 'Armstrong'.

Significantly better than average wound-closure rates were observed on the following cultivars: 'Autumn Flame', 'Autumn Glory', 'Doric', 'Red Sunset', and 'Schlesinger' (Table 1 and Fig. 3). In this study, 'Autumn Glory' seemed to close wounds especially rapidly, even though it has not been a traditionally fast-growing cultivar. After growth data for the 1980 growing season are collected, it should be easier to define interaction between growth rate and cultivar effect on closure rates. Growth rates and wound-closure rates vary according to environmental conditions. It is possible that cultivar effect also varies with environmental conditions; however, this must be substantiated by further tests.

Cultivars closing wounds at a significantly slower than average rate include 'Armstrong', 'Bowhall', 'Gerling', and 'October Glory'. 'October Glory' yielded an extremely poor closure response. This is again quite interesting, considering the fact that 'October Glory' has been above average in growth rate since 1965 in the Shade Tree Evaluation Plot.

In light of the cultivar variation in wound closure rate, it would be wise to give primary consideration to those with above average wound response. This should be especially important for commercial sites where trees are subject to a high degree of mechanical abuse. In addition to aesthetics, rapid closure would leave the wound susceptible to decay organisms for a shorter period of time. It has further been shown that once the wound is closed, the decay process itself ceases to advance (10).

There is still much to be done in this area, but with this study the area is opened to further research directed toward the selection of tree cultivars on the basis of superior wound-closure response. Additional steps to be taken in this area include: 1) continuation of this study, correlating growth data with wound-closure performance; 2) further selection on the basis of internal compartmentalization as well as wound-closure, and 3) expansion of the project to include screening of additional species and cultivars.

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Preventing Habitual Iron Chlorosis of Woody Landscape Plants[1]

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ABSTRACT

Treatment with systemic iron implants into stem, trunk, or limbs of shrubs and trees has prevented chlorosis of numerous species of woody landscape plants. Included among the plants habitually chlorotic and responding positively to ferric ammonium citrate treatment were: *Betula nigra, Betula pendula, Cornus florida, Cornus kousa, Halesia caroliniana, Hamamelis vernalis, Liquidambar styraciflua, Magnolia stellata, Magnolia virginiana, Photinia villosa, Pinus strobus, Quercus alba, Quercus coccinea, Quercus palustris,* and *Quercus phellos.* Iron implants increased the chlorophyll level, iron content, and visual response of the foliage when compared to untreated plants.

INTRODUCTION

Iron in the soil is often in an unavailable form for plant utilization due to an alkaline pH, poor soil aeration, unfavorable drainage, and/or chemical imbalances. Consequently, many woody landscape species become yellow or chlorotic due to a lack of chlorophyll development, and with some species the plants defoliate with eventual twig dieback and occasionally plant death.

Several research papers have reported investigations of chlorosis caused by iron deficiency (1, 2, 4, 12). Dependable and repeatable success in overcoming chlorosis in woody landscape plants was not achieved until systemic nutrients became available (3, 5, 6, 7, 8, 9, 10, 11). Changing the pH under trees in the landscape is difficult, foliar treatments are seasonal in effect, and iron added to the soil has not been long-lasting in preventing chlorosis.

The studies reported in this paper summarize the research conducted between 1975 and 1980 on the response of woody landscape trees and shrubs to systemic iron implants. The objectives of these studies were to determine which species develop habitual iron chlorosis and to evaluate their response to iron treatments.

MATERIALS AND METHODS

Ferric ammonium citrate capsules containing 28% Fe were implanted into stems, trunks, or limbs of individual branches of trees in order to compare treated with untreated areas of the same plant. Except for oak species, nearly all capsules were implanted in late March or early April prior to leaf emergence on plants growing in landscape sites in central Ohio with a soil pH range of 6.5 to 7.5. Oaks were treated in both the dormant and early summer seasons.

Capsules were implanted in a spiral pattern around the tree or shrub at a spacing equal to trunk diameter in inches minus two. The capsules were either 3/8 or 1/2-inch in diameter and were inserted into the wood tissue beneath the bark and cambium. Tree wound dressings were not applied to the wounded area.

Plants were evaluated for visual color on a 1-10 scale, total chlorophyll content measured in mg/g of leaf tissue, and iron levels evaluated by mass spectrography. All evaluations of foliar color were made in September, with 10 representing a dark green leaf, 7 an acceptable green, and 1 defoliation.

RESULTS AND DISCUSSION

Betula pendula: **European Birch** is often chlorotic in the landscape and response to iron treatments has been successful (Table 1). However, the chlorosis must be caused by a deficiency of iron, and not related to bronze birch borer, leaf miner, or Japanese beetle injury. Positive visual results to iron have also been noted with *Betula nigra,* River Birch, in limited trials.

Wound closure in birch is moderate and dependent on vigor of the tree.

Cornus florida, **Flowering Dogwood,** and ***Cornus kousa,*** **Kousa Dogwood:** These dogwoods growing in high pH soils are frequently chlorotic and this chlorosis can be prevented with iron implants (Table 1). Chlorosis caused by borers or canker cannot be prevented with systemic nutrients, so investigative work is often necessary to determine the causal agent prior to treatment.

Wound closure of *Cornus* species is moderate to rapid when treated in March or early April.

Halesia caroliniana: **Carolina Silverbell** is a small tree that is not commonly grown in central and western Ohio due to its iron chlorosis problems. Trunk implantations resulted in marked improvement in foliage color and chlorophyll content (Table 1).

Wound closure rate was moderate from March treatments.

Hamamelis vernalis: **Vernal Witchhazel** in alkaline soils often becomes almost white from iron deficiency, particularly on summer growth. Since iron is non-mobile in the plant, the spring growth is norm-

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ally green and the summer growth yellow to white. Response to iron implants of 3/8-inch diameter on the larger canes has resulted in prevention of chlorosis (Table 1).

Wound closure has been satisfactory from early spring treatments.

Liquidambar styraciflua: **Sweet Gum** will respond to iron treatment more positively when the chlorosis is extensive but results may be minimized if chlorosis is mild or scattered on the tree. In all of the 15 trees reported in Table 1, the yellowing of foliage was moderate to extensive on the tree.

Closure of wounds in Sweet Gum is slow and two growing seasons may be necessary for complete closure. Bleeding of Sweet Gum is common in the dormant period following the drilling and implant treatments.

Magnolia stellata, **Star Magnolia,** and ***Magnolia virginiana,*** **Sweet Bay Magnolia:** Both have responded well to iron implant treatments (Table 1). These species are both typically grown multi-stem and until plants have been growing for a number of years, implant treatments may not be practical on the small diameter stems. Foliar treatments of chelated iron may be the preferred treatment on small plants.

Wound closure from 3/8-inch capsules has been rapid with both these magnolia species.

Photinia villosa: **Oriental Photinia** is occasionally found in the landscape in Ohio and when it is, it's

TABLE 1.—Landscape Plants Responding Positively to Iron Implants.

Plant Material	Number of Plants	Visual Response	Chlorophyll Content mg/g	Iron Content ppm
Betula pendula				
Iron treatment	3	9	3.13	103.2
Control	3	4	1.91	92.2
Cornus florida				
Iron treatment	3	7	1.79	96.0
Control	3	4	1.16	76.4
Cornus kousa				
Iron treatment	3	8	3.07	118.6
Control	3	5	2.20	116.8
Halesia caroliniana				
Iron treatment	3	8	4.29	115.9
Control	3	4	2.55	111.4
Hamamelis vernalis				
Iron treatment	6	8	1.97	112.6
Control	6	4	1.39	66.7
Liquidambar styraciflua				
Iron treatment	15	8	2.85	
Control	15	4	1.72	
Magnolia stellata				
Iron treatment	6	9	2.73	
Control	6	6	1.13	
Magnolia virginiana				
Iron treatment	6	10	3.35	133.0
Control	6	5	1.67	69.2
Photinia villosa				
Iron treatment	3	7	2.48	
Control	3	5	1.13	
Pinus strobus				
Iron treatment	12	8	2.25	461
Control	12	4	1.56	331
Quercus alba				
Iron treatment	10	8	2.23	210
Control	10	3	1.58	154
Quercus palustris				
Iron treatment	24	9	1.78	161
Control	24	4	1.27	139

FIG. 1.—Sweet Gum chlorosis. The dark green veins and yellow interveinal areas are typical symptoms of iron deficiency.

likely to be quite yellow. Implants of ferric ammonium citrate improved the foliage color and chlorophyll content (Table 1).

The rate of wound closure in *Photinia* is moderate.

Pinus strobus: White Pine in central and western Ohio is often chlorotic, resulting in short and curled needles. Complete tree treatments of iron implants resulted in darker green trees up to 3 years following treatment (6), along with higher chlorophyll and iron levels (Table 1).

Wounds from ½-inch openings close in one season in most trees but are always accompanied by ooze of resin which deposits a white residue on the trunk.

***Quercus palustris,* Pin Oak,** and ***Quercus alba,* White Oak:** These are the two *Quercus* species showing the most positive response to ferric ammonium citrate treatment (Table 1). Other oaks, typically less chlorotic but showing response, include *Quercus coccinea,* Scarlet Oak, and *Quercus phellos,* Willow Oak. Generally, prevention of chlorosis can be observed in oaks for 2 to 3 years except in severely chlorotic trees which may require annual applications.

Normally a 90% success rate in oaks can be obtained from March-April treatments, but less than 50% appreciable recovery can be expected from June or July treatments.

In one growing season, complete closure of wounds can be expected in oaks from a ½-inch wound in the dormant season, but only partial closure can be expected from summer treatments.

Systemic treatments for iron chlorosis improve foliage color and improve the vigor of treated trees. Although wounding trees is not desirable, trees left untreated may continue to decline and eventually die.

Iron implants cannot be expected to correct all chlorosis problems; thus it is important to obtain a correct diagnosis initially. A soil and leaf analysis will be helpful in diagnosing nutrient problems.

Chlorotic trees, in addition to being treated with iron or the proper element, should also be regularly fertilized with a nitrogen, phosphorus, and potassium fertilizer, watered when necessary, and kept pest free.

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Boron Toxicity in Woody Ornamentals

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ABSTRACT

Boron (B) toxicity is characterized by leaf tip yellowing followed by apparent leaf tip necrosis and premature defoliation. Both root and shoot growth are suppressed when B is present in excessive amounts. Critical foliar toxicity levels for B appear to be between 85-100 ppm of dry tissue. Apparent causes and procedures to avoid B toxicity are discussed.

INTRODUCTION

During the past year, several cases of boron toxicity have been identified in containerized nurseries producing woody ornamentals. In all cases of B toxicity, symptoms became visible between mid-summer and late autumn. Since boron is a relatively immobile element within the plant and moves primarily in the xylem, more uptake occurs during warm, dry months of the year.

The early symptoms of B toxicity on grower samples of both Rhododendron and Taxus were characterized by leaf-tip yellowing. This agrees with reported data on other crops (1, 2, 4). As the toxicity progressed, marginal chlorosis was observed with Rhododendron, followed by tip burning and premature leaf drop. With Taxus, no marginal chlorosis developed. Leaf tips turned yellow and tip burn followed. Often it appeared that the leaf tips or margins had been scorched or burned. In some cases of severe toxicity, the tips turned brown almost immediately. The locations of the injury symptoms occur because B is transported in the transpiration flow and accumulates in the leaf tips and margins as water is lost to the atmosphere (4, 5).

If the B toxicity is not corrected, new growth the following season may be affected. Terminal growth is generally rosetted or twig dieback occurs. Leaves are dwarfed, curled, and arise from shortened internodes. Flower buds, if present, generally die with acute B toxicity.

Early stage symptoms of B toxicity are similar to those produced by numerous other conditions including overwatering, soluble salts, etc. As a result, the first step to correcting a potential B problem is to analyze foliar tissue to positively identify if B toxicity exists.

MATERIALS AND METHODS

In this study, to determine critical foliar toxicity, uniform 2-year-old liners of *Taxus media* 'Anderson' were potted into 3-liter plastic containers on Nov. 30, 1978, in two different media, pinebark and sand (4:1 v/v) and hardwood bark and sand (4:1 v/v). Both media were amended according to current recommendations (3). These plants were grown in a greenhouse at approximately 26° C day/21° C night. Incandescent lights were used to extend the photoperiod from 10 p.m.-2 a.m. Four weeks after potting, weekly fertilization was commenced using a water soluble fertilizer (20 N to 8.7 P to 16.7 K) at the rate of 150 ppm N. This frequency and rate of fertilization were continued throughout the study.

On March 15, 1979, four B treatment levels were initiated: 0.5, 5.0, 25.0, and 50.0 ppm B in the form of boric acid. Each week 250 ml of each respective treatment were applied. As a result of severe defoliation, treatments of 25.0 and 50.0 ppm B were not applied after June 19, 1979. Six, 12, and 24 weeks after the initial treatments, tissue samples were collected from the terminal 5 cm of growth. All tissue samples were analyzed at the end of the experiment. A randomized block experimental design was used with four replications of six plants each.

RESULTS AND DISCUSSION

Boron toxicity symptoms were apparent on plants treated with 25 and 50 ppm B at the first sampling date. Foliar symptoms of B toxicity on *Taxus* were characterized by leaf-tip yellowing followed by leaf-tip necrosis and premature defoliation. With the highest rate of applied B, some leaf tips were necrotic within 2 weeks.

Plants grown in both media at 25 ppm B, which had just begun to exhibit symptoms of B toxicity when tissue samples were collected on April 25, had a B concentration of approximately 100 ppm of dry tissue (Table 2). This would concur with reported B toxicity on grower samples with concentration in ex-

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TABLE 1.—Boron Content of Taxus Grown at Four Boron Levels in Two Media at Three Dates During a Grow-in Season.*

Boron Level (ppm)	Time 1†		Time 2		Time 3	
	Hardwood Bark	Pinebark	Hardwood Bark	Pinebark	Hardwood Bark	Pinebark
0.5	36‡	28	48	36	46	60
5.0	35	40	60	40	85	83
25.0	96	100	301	253	168**	107
50.0	232	222	730	364	293	302

*Media—Hardwood bark:sand 4:1/v:v; Pinebark:sand 4:1/v:v.
†Time 1, April 25, 1979; Time 2, June 7, 1979; Time 3, September 17, 1979.
‡$LSD_{0.05}$ is equal to 23.2 for rows and columns.
**Treatments 25 and 50 ppm were discontinued after June 19, 1979. Time 3 data represent B accumulation from B in media from earlier treatments.

cess of 100 ppm. Plants receiving 0.5 and 5 ppm B did not exhibit B toxicity symptoms at any time during the experiment.

These data also show that even when B treatments were discontinued, B concentration in the new terminal growth was still in a toxic range. This indicates that over-fertilization with B may have long term effects on plant growth, and that normal watering will not leach out excess B. In this study, growth of two flushes was affected on plants grown at 25 and 50 ppm B, the growth flush occurring during treatment application and the growth flush following the termination of B treatments. Furthermore, these data show that B continues to accumulate in the tissue well after a critical level of B is reached. The ability of plants to recover from B toxicity without affecting subsequent growth flushes may be dependent on the quantities of B accumulated in the tissue.

Combined analysis of the two media over three sampling dates showed that Ca, Mn, and Zn foliage concentration were lower when plants were grown with 25 and 50 ppm B (Table 3). Generally, it is accepted that one of the functions of Ca in plant nutrition is that of preventing micronutrients from being toxic (6, 7), and when determining phytotoxicity level of micronutrients, the Ca status of the plant must be considered. Lower levels of Ca at the higher B rates may have increased the susceptibility of these plants to B toxicity.

Sources of Boron: Most B toxicity problems in the nursery industry are caused by over-fertilization with B-containing fertilizers. The major source of B in a container medium is the micronutrient fertilizer. Seven micronutrient sources are presented in Table 3, and four of these have B levels of 1,000 ppm or higher. These sources alone will not generally produce B toxicity because the B becomes available over an extended period of time.

Many of the other preplant mix ingredients contain B. For example, in Table 4 a number of com-

TABLE 2.—Mineral Element Composition of Taxus Grown at Four Boron Levels.

	N	P	K	Ca	Mg	Na	Mn	Fe	B	Cu	Zn	Al
B ppm			%						ppm			
0.5	2.1	0.23	2.1	0.84	0.19	30	130	39	48	6.4	66	20
5.0	2.1	0.23	2.1	0.77	0.18	31	121	38	67	6.6	58	20
25.0	2.0	0.23	2.1	0.59	0.18	34	92	31	171	6.5	50	9
50.0	2.0	0.24	2.1	0.66	0.18	39	100	33	357	6.4	52	15
$LSD_{0.05}$	NS	NS	NS	0.05	NS	NS	9	3	16	NS	3	4

TABLE 3.—Mineral Element Composition of Several Micronutrient Sources, in Percent by Weight of Packaged Product.*

	Perk	Esmigran	FTE 503	FTE 504	STEM	Lesco-Fe Plus	Micro Max
Boron	0.02	0.02	3.0	3.8	1.45	0.05	0.1
Iron	3.7	2.0	18.0	14.0	7.5	5.0	12.0
Manganese	2.2	0.5	7.5	7.0	8.2	0.5	2.5
Zinc	0.7	1.0	0.05	7.0	4.5	1.0	1.0
Copper	0.2	0.3	3.0	7.0	3.2	0.5	0.5
Molybdenum	0.002	0.0006	0.2	0.07	0.046		0.005

*1 % = 10,000 ppm

TABLE 4.—Common Sources and Levels of B in Fertilizers Used in a Preplant Medium for Container Production.

Source	Lb/Yd³	g/2 Gal Container	g/100 g B	mg B/2 Gal Container
Urea formaldehyde	4.4*	14.98	0.0000024†	0.036
Iron sulfate	0.8	2.7	0.000642	1.733
Gu 49 (micronutrient)	2.0	6.8	0.001950	13.260
Dolomitic limestone	4.0	13.6	0.00004	0.544
Triple superphosphate	1.8	6.1	0.000328	2.001
Gypsum	3.2	10.9	0.000140	1.526
				19.145

*Rate of fertilizer incorporated into the preplant medium.
†Samples were digested in 6N HCL for 4 hours at 90° C.

mon preplant ingredients are listed with the rate per cubic yard of medium, percent B, and the grams of B per container. Clearly, some of the fertilizers are quite high in B. For example, one pinebark medium studied contained 0.25 ppm B, and Canadian peat contained approximately 0.06 ppm B. In many cases, total B may exceed 20 milligrams per container when all additives are considered.

Avoiding Boron Toxicity: One way to avoid B toxicity is to select a micronutrient fertilizer without B or one with low B levels. Data in this study show that adequate B is available as impurities in preplant medium ingredients (Table 4) and is not needed in the micronutrient fertilizer.

Boron toxicity may also be minimized by proper pH levels. Availability of B decreases as the pH increases. If B toxicity has been a problem, a pH range of 6.0 to 6.5 may adequately correct the problem. Most B toxicity problems occur when the pH is in the 4.5 to 5.5 range. As a result, B toxicity is often seen on plants grown in that pH range (rhododendrons, azaleas, etc.).

To further complicate the problem of B toxicity, post-plant fertilizers may contain B. For example, Peters standard fertilizer (20-20-20) has 0.0068% B which means that when 200 ppm N is applied, approximately 0.068 ppm B is also applied. Some slow release fertilizers also contain B. Growers with B problems should request from the technical representative of the fertilizer company the data on B levels; however, many technical representatives are not aware of the B present in their product. Government regulation for fertilizers only covers minimum levels in the fertilizer bag. Furthermore, the state agency which monitors fertilizers may not test for B, as is the situation in Ohio.

SUMMARY

As a result of the lack of information on B present in many fertilizers, growers who have experienced B toxicity problems should have new medium additives checked for B levels. Boron toxicity can be avoided by proper choice of micronutrient or by maintaining proper medium pH. Boron toxicity can be identified early by foliar analysis. Critical foliar toxicity levels are 85-100 ppm.

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